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PARAMETRIC DESIGN STRATEGY AIMING AT ENVIRONMENTALLY SUSTAINABLE RESIDENTIAL BUILDINGS

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Summary

This paper presents the preliminary conclusions from a PhD study about methodical approaches to environmentally sustainable architecture. The presented results are from a local sensitivity analysis focused on the energy consumption of a typical residential reference building, when it is subjected to a parametric study of the impact of changes in input parameters relating to the design and the use of the building.

Keywords: Parametric design, inter-disciplinarity, prioritisation of design parameters, sensitivity analysis, energy, design strategy, residential buildings

1 Introduction

Most research in the field of environmental and sustainable architecture point out a need for design strategies which consider technical strategies and solutions early on in the design process. [1-5]. This need for early implementation of technical strategies and solutions calls for a study of which design parameters have the greatest influence on the environmental impact of a building, and thus their influence on decision-making in the design process of an environmentally sustainable building.

This paper presents the preliminary results of a PhD study with the work title ‘Methodical Approaches to Environmentally Sustainable Architecture’, in which design parameters applied in residential building projects are subjected to a sensitivity analysis of the design parameter’s impact on the energy consumption of a building, whilst considering indoor comfort. These results are condensed in a design strategy for residential buildings in Denmark. The paper also contains a short discussion of inter-disciplinarity in relation to existing methodical approaches to integrated design.

2 Inter-disciplinarity and integrated design

Within the last decade descriptions of integrated design processes have been formulated in a number of publications. The most relevant of these, from an environmentally sustainable point of view, are the ones presented in Lönert, Dalkowski and Sutter 2003 ([9]) and Knudstrup 2004 ([3]). The process descriptions presented in these publications can be characterised as having inter-disciplinary approaches to integrated design. In both publications the process is presented as an iterative process with several loops, and both publications focus on the importance of teamwork. The inter-disciplinarity is, however, viewed differently in these two publications. In [9] inter-disciplinarity takes place between the different actors representing the different disciplines, whilst in [3] inter-disciplinarity occurs through the development of a new type of education that mixes the disciplines of architecture and building engineering. The inter-disciplinarity is, thus, in this case embedded in one actor, or in a group of actors with similar disciplinary backgrounds.

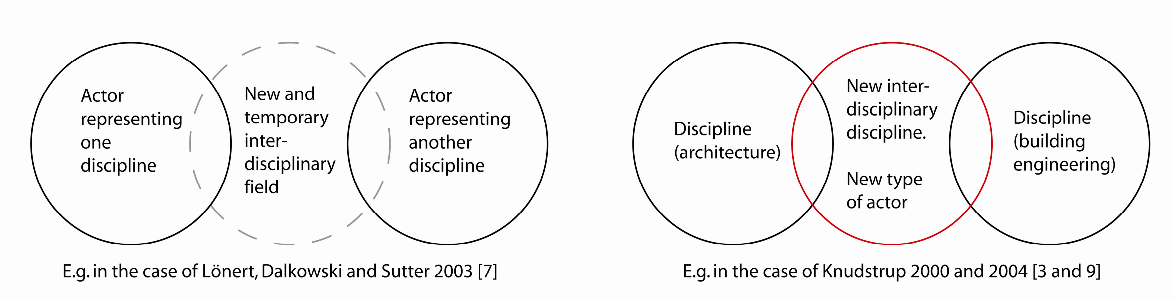

Fig. 1 Differences in the understanding inter-disciplinarity (inspired by Schmidt 2007)

The difference in ideas of how inter-disciplinarity occurs is, thus, significant. The approach to inter-disciplinarity presented by [3] does, however, not exclude the approach presented by [9], as the new discipline created in [3] can function along side other disciplines in new temporary inter-disciplinary fields.

The outset of the PhD study has been the inter-disciplinary field between two groups of actors (as shown on the left-hand side), and the author of the PhD project belongs to the new type of inter-disciplinary discipline shown on the right-hand side of the illustration.

3 Sensitivity Analysis

The sensitivity analysis presented in this paper is a local sensitivity analysis of the OAT (Once At a Time) variety [6].

The analysis focuses on new residential building projects in a Danish context (both climatically and architecturally), and the aim of the analysis has been to enable an informed decision-making process in the early stages of the design process where the design concepts and strategies for the project are decided.

The methodical approach chosen in the PhD study presupposes a parametric approach to the decision-making process in which the aim is to uncover which design parameters are most influential on the energy consumption.

3.1 Methodology

Sensitivity analyses are basically statistical ways of producing and analysing data, and they are, thus, applied in many different fields. The analyses are usually performed to determine the sensitivity of parameters and/or the importance of parameters (uncertainty analysis) [6].

The sensitivity of parameters are interesting when one needs to choose which parameters to focus on in a project. The importance of parameters are interesting when one has to prioritise a number of parameters in a decision-making process. In such cases it is interesting to attain knowledge of which parameters are most important to consider.

It it interesting to note, that important parameters are always sensitive, as the sensitivity of a parameter will cause it to be important [6].

The process involved in this local sensitivity analysis has consisted of 6 stages:
1) Choice of reference building. 2) Choice of which programme to build the model in and what to investigate. 3) Selection of the input parameters. 4) Ranges were set up for the input parameters. 5) Local sensitivity analysis where the input parameters were changed individually in accordance with the ranges. 6) Analysis of the results of the local analysis and an preliminary ranking.

3.2 Model

The model is based on a reference building inserted into a Danish computer programme (Be06). The programme was designed for demonstrating the legitimacy of Danish building projects with respect to the new energy requirements introduced to the Danish building codes in April 2006. In this project the programme is treated as a tool, which can be utilised as a decision-making tool in the design process.

The Be06 programme considers the following contributions to the energy consumption:
Heating, cooling, heat loss installations, boilers, heat pumps, solar panels, pumps, ventilators, refrigerator, lighting, photo voltaic cells, other electrical consumptions for building operation. [7]

The reference building is a standardised one family home in Denmark with an annual energy consumption of 86.1 kWh/m^{2}K, which is just enough to pass the legislative approval.

3.3 Input parameters

The input parameters were derived from existing publications found in the field of environmental and sustainable architecture, as well as from experience gained in previous projects.

Based on this the following input parameters were selected:
Solar shading (window placement in the depth of the façade, size of overhang, permanent shade at windows, shade from surroundings), **Window type, area and angle, Building orientation** (rotation), **Wall, floor and roof insulation** (U-values), **Thermal mass, Ventilation** (comfort criteria and heat recovery), **Building shape** (room height, surface to floor area ratio for a one storey building, no. of vertical corners and no. of storeys)

and **User** (internal heat gains from people and installations, consumption of hot water, comfort temperature).

In this study the input parameters are assumed to be independent, due to the nature of the OAT analysis [6].

After deciding the input parameters the ranges for each parameter were chosen in accordance with legislative demands, comfort criteria and general design criteria applied in form finding process.

3.4 Results

The investigated parameters were varied one at a time in the model and the resulting energy consumptions were recorded. In order to procure some information about the importance of the parameters a calculation of how the results of each parameter deviated from the energy consumption of the reference building. The resulting deviation percentages are showed in **Tab. 1**, along with the ranges of the input parameters, and the maximum and minimum deviation percentages. Table 1 only shows the parameters with the largest deviation, which are considered to be the most influential parameters.

Tab. 1 The most influential design parameters

Input arameter	Results			Range of input parameter
	Deviation %	Maximum deviation %	Minimum deviation %	
User – comfort temperature	81.42	**64.81**	**-16.61**	18 to 26 degrees C
Building shape - Room height	51.10	**38.68**	**-12.43**	2.5 to 4.5 meters – average room height
Ventilation – heat recovery	50.64	**4.99**	**-45.64**	0 to 100% heat recovery
Window area – glass ratio north facade	48.66	**42.97**	**-5.69**	0 to 100% glass area on north facade. The rest of the facades are the same as in the reference building
Window area – glass ratio all facades	46.34	**40.65**	**-5.69**	0 to 50% glass area on all facades
Building shape – no. of storeys	41.31	**0.00**	**-41.31**	0 to 11 storeys
Insulation – roof	37.63	**27.18**	**-10.45**	U-values: 0.05 to 0.4 W/m^{2}K)
Window area – glass ratio west facade	33.80	**32.87**	**-0.93**	0 to 100% glass area on west facade. The rest of the facades are the same as in the reference building
Shade – surroundings	30.89	**27.64**	**-3.25**	0 to 90 degrees
Insulation – walls	29.85	**17.31**	**-12.54**	U-values: 0.05 to 0.4 W/m^{2}K
Window area – glass ratio south facade	28.69	**29.97**	**1.28**	0 to 100%
User – electricity	27.87	**11.73**	**-16.14**	1.53 to 6.13 W/m^2
Insulation – floor	26.13	**18.82**	**-7.32**	U-values: 0.05 to 0.4 W/m^{2}K
Window type	24.51	**15.68**	**-8.83**	Different types of VELFAC windows
Window area – glass ratio east facade	21.72	**18.47**	**-3.25**	0 to 100%
User – hot water	19.98	**10.57**	**-9.41**	109 to 438 l/year pr m^2

The maximum deviation percentage corresponds with the maximal increase caused in the energy consumption of the building, while the minimum deviation percentage corresponds with the maximal decrease in the energy consumption of the building, when changing the parameter to the boundary values of its range.

The minimum deviation percentages, thus, show the optimisation potential for the reference building, while the maximum deviation percentage shows the risks of increasing the energy consumptions by making an uninformed decision. The results in both tables should, thus, be seen in relation to the design of the reference building.

4 Conclusions

When looking at the deviation percentages shown in table 1 one can conclude, that the way the building is used, the shape of the building, installation of heat recovery in the ventilation system, the increase of window areas in different directions or in all directions, as well as the insulation of the building envelope have a great impact on the energy consumption. This is not surprising news, but how the deviations are distributed (in accordance with the size of the deviation) may come as a surprise.

Interesting conclusions in relation to the building shape are, that:

- it is the number of storeys and the average room height that have the largest impact on the energy consumption
- that there is a balance point around 3 to 4 storeys, at which the benefits of increasing the number of storeys are no longer large
- that the number of vertical edges/corners was the least influential parameter, closely followed by the surface to floor area ratio for one storey .

At this point in the PhD study, the preliminary results indicate that a design strategy for new environmentally sustainable residential buildings in Denmark would be to choose:

- mean values for the insulation of the building envelope (0.2 kWh/m^2K or less).
- 20 to 40 % window area facing southern, eastern and western directions
- Minimise window area facing north
- Introduce heat recovery in the ventilation system
- Consider building more than 1 storey (preferably 3 to 4)
- Consider how to induce environmental awareness in the user of the building. E.g. by placing meters next to the electric outlets or next to the taps.

The conclusions made in this preliminary study with respect to energy must be evaluated in relation to the possibilities and restrictions they cause on the decision-making process in relation to other design criteria, such as physical and psychological comfort, functionality, aesthetics etc. before they are applied in a design process.

Furthermore it is important to be aware, that this sensitivity analysis only provides results about what happens when the parameters are changed one at a time.

With the recent introduction of stricter energy requirements for buildings in EU and with the prospect of further reductions in the permitted energy consumption, architects and engineers must apply more than one of the parameters to their projects to achieve acceptable levels of energy consumption. The next step is, thus, to change groups of parameters together, to see how this influences the ranking of the parameters.

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